For assistance with 508 accessibility, please reach out to Anna Miller (email: miller.anna@epa.gov, phone: 312-886-7060)

AREA OF REVIEW AND CORRECTIVE ACTION PLAN
40 CFR 146.84(b)

ONE EARTH CCS

Facility Information

Facility name:	One Earth CCS OES #1
Facility contact:	Mark Ditsworth VP of Technology and Special Projects One Earth Sequestration, LLC 202 N Jordan Drive, Gibson City, IL, 60936, (217) 784-5321 ext. 215
Well location:	McLean County, Illinois Coordinates: 40.845427°N, -88.480010°W (NAD 1983)

Computational Modeling Approach

Model Background

The Illinois State Geological Survey (ISGS) developed the model (named TRiINJ) using Petrel and Nexus software. The purpose of the model is to predict the CO_2 plume and pressure fronts to define the Area of Review (AoR).

The computational modeling is based on porous media theory (Darcy's Law). The CO_2 properties are based on the Peng-Robinson equation of state. The process modeled is brine and CO_2 (gas and liquid) using relative permeability, including residual trapping. The geocellular model includes permeability variations that affect the multifluid flow process influencing the CO_2 plume and pressure front.

Site Geology and Hydrology

A detailed description of site geological and hydrogeological characteristics is contained within the CLASS VI NARRATIVE document. The One Earth Energy #1 (OEE #1) site-specific data available for geology and hydrology properties used in the computational model are as follows: core, core porosity and permeability, and well log porosity and permeability.

The Eau Claire Formation (primary confining unit), the Mt. Simon Sandstone, and the Argenta are included in the models.

Injection Zone

The Mt. Simon Sandstone is the injection zone. Sensitive, Confidential, or Privileged Information [redacted]

At or near the base of the lower Mt. Simon is an arkose interval which generally has good to excellent porosity and permeability (p&p). Regionally, the lower and upper Mt. Simon have good to excellent p&p and the middle Mt. Simon has poor p&p. Below the lower Mt. Simon Sandstone is the informally named Argenta sandstone, which is generally very low p&p. Sensitive, Confidential, or Privileged Information [redacted]

The upper Mt. Simon is composed of fine- to coarse-grained quartz sandstones, interbedded with massive to finely planar laminated feldspar sandstones. Sensitive, Confidential, or Privileged Information [redacted]

Sensitive, Confidential, or Privileged Information [redacted]

[redacted]

The depositional environment of the Mt. Simon Sandstone and similarity in rock characteristics areally demonstrate the lateral continuity of the Mt. Simon over a large region of central Illinois (Figure 1). (See REGIONAL GEOLOGY document.) The arkose interval is present in each of the wells across a multi-county area (Figure 2).

In OEE #1, the Mt. Simon Sandstone water salinity is 166,000 mg/L (ppm), which is consistent with regional mapping of salinity data for the Mt. Simon Sandstone in the Illinois Basin.**Error! Reference source not found.**

Sensitive, Confidential, or Privileged Information

[redacted]

Figure 1. Isopach map of Mt. Simon Sandstone and Argenta sandstone thickness. Black star identifies OEE #1. The map corner coordinates (Decimal Degree NAD83) are: NE: -82.340550, 43.842385; SE: -82.824731, 36.384301; SW: -91.527664, 36.371440; NW: -92.052323, 43.825652.

Sensitive, Confidential, or Privileged Information

[redacted]

Figure 2. Stratigraphic cross-section of the Mt. Simon (lower right inset). The pink highlighted section is the Precambrian surface. Datum: base of Eau Claire. Coordinates (Decimal Degree NAD83) of the northernmost well are -88.918922, 40.683164, and coordinates of the southernmost well are -89.203412, 39.772784.

Confining Zones

The Eau Claire Formation is the confining zone. The Eau Claire underlies all of Illinois, ranging from less than 300 feet (91 meters) thick to more than 1,000 feet (305 meters) (Buschbach, 1964).

Sensitive, Confidential, or Privileged Information [redacted] The Eau Claire Formation is primarily clay-rich shale.

Model Domain

Schlumberger's Petrel (version 2021) was used to create a static geocellular model that includes the structure and petrophysical properties of the injection zone and confining zone. Landmark's Nexus (version 5000.4.14) was used to refine cells in the center of the model and simulate CO_2 injection.

The model is 20 × 20 miles (32 × 32 kilometers) laterally, with an average thickness of 2,977 feet (907 meters). The model has 106 ×106 × 143 cells, each cell is 1,000 × 1,000 feet (305 × 305 meters) areally; the cell thickness varied from 2.5 feet to 179 feet (0.76 meters to 54.6 meters), averaging 21 feet (6.4 meters). Local grid refinement was applied to an 8 × 8 mile (12.9 × 12.9

kilometers) area including all project wells. Each 1000 x 1000 feet cell was refined into 4 250 × 250 feet cells.

Model domain information is summarized in Table 1.

Table 1. Model domain information

Coordinate System	NAD 27 Illinois State Plane, Eastern Zone, US Foot (SPCS27 1201)		
Horizontal Datum	North American Datum of 1927		
Coordinate System Units	US Foot		
Zone	Illinois East		
FIPSZONE	1201	**ADSZONE**	-
Coordinate of X min	408000	**Coordinate of X max**	-
Coordinate of Y min	1339500	**Coordinate of Y max**	-
Elevation of bottom of domain	-6,548 (ft)	**Elevation of bottom of domain**	-

Porosity and Permeability

The OEE #1 (i.e. site-specific) data used for determining p&p includes laboratory core measurements and geophysical logs (neutron porosity, nuclear magnetic resonance logs, and resistivity logs). Data from two additional wells in the model domain was used: Hinton Brothers #7 (core p&p, and logs) and Furrow #11 (logs). The range of porosity and permeability observed at the OEE #1 was similar to that of the Furrow #11 and the Hinton Brothers #7.

Neutron porosity logs provided the best calibration to core porosity. A permeability log was created from the core-calibrated porosity log calibrated to core permeability. The permeability log for the OEE #1 used the NMR log and the Schlumberger Doll Research method. The permeability log for the Hinton Brothers #7 and Furrow #11 wells used each well's porosity and resistivity logs.

The Eau Claire is described as constant porosity (4.5%) and permeability (0.0001 md).

Within the injection zone at OEE #1, the core spatial distribution vertically varies between ~0.5 feet to ~30 feet. Laterally, OEE #1 is 15.5 miles (24.9 kilometers) from the Hinton Brothers #7, and 27.5 miles (44.3 kilometers) from the Furrow #11 (Figure 3).

Sensitive, Confidential, or Privileged Information

[redacted]

Figure 3. Map showing the location of wells used to determine porosity and permeability for the injection and confining zones. Coordinates in IL State Plane East NAD27 are notated on the map.

Figure 4 and Figure 5 show porosity and permeability distributions from the three wells used to populate the static models. Within the arkose interval, the porosity range is 6-28% and horizontal permeability range is 0.05-1,970 mD. The model's porosity (Figure 6 and Figure 7) and permeability (Figure 8 and Figure 9) were distributed using sequential gaussian algorithm and lateral distributions consistent with the geologic conceptual model.

Sensitive, Confidential, or Privileged Information

[redacted]

Figure 4. Porosity and permeability distributions in the upper, middle, and lower Mt. Simon zones. Data are from the three well locations OEE #1, Hinton Brothers #7, and Furrow #11.

Sensitive, Confidential, or Privileged Information

[redacted]

Figure 5. Porosity and permeability distributions in the Arkose and Argenta zones. Data are from the three well locations OEE #1, Hinton Brothers #7, and Furrow #11.

Sensitive, Confidential, or Privileged Information

[redacted]

Figure 6. Porosity of the top model layer (plan view) of the Arkose interval. The model area (red box) corner coordinates (Decimal Degree NAD83) are approximately: NE: -88.28289, 40.635788; SE: -88.28289, 40.344361; SW: -88.66480, 40.344361; NW: -88.66480, 40.635788.

Sensitive, Confidential, or Privileged Information

[redacted]

Figure 7. North-South vertical cross-section of the porosity model through OEE #1 (north to left). Vertical exaggeration is ~10x.

Sensitive, Confidential, or Privileged Information

[redacted]

Figure 8. Permeability of the top model layer (plan view) of the Arkose interval. The model area (red box) corner coordinates (Decimal Degree NAD83) are approximately: NE: -88.28289, 40.635788; SE: -88.28289, 40.344361; SW: -88.66480, 40.344361; NW: -88.66480, 40.635788.

Sensitive, Confidential, or Privileged Information

[redacted]

Figure 9. North-South vertical cross-section of the permeability model through OEE #1 (north to left). Vertical exaggeration is ~10x.

Constitutive Relationships and Other Rock Properties

Three sets of Corey generated (Corey, 1954) relative permeability representing high- (permeability greater than 100 mD), mid- (permeability between 1 mD and 100 mD), and low-quality rock (permeability less than 1 mD) were used (Figure 10). The high-quality rock relative perm was based on lab measurements of lower Mt. Simon rock from Decatur area wells. The relative permeability data of mid- and low-quality rocks were generated based on the high-quality relative permeability and principle that that irreducible water saturation increases and movable saturation range decreases as permeability decreases.

Rock compressibility (5.61×10^{-6} psi^{-1}) was estimated using Newman's correlation for sandstone (Newman, 1973) for 11.4%, the average porosity of the Mt. Simon and Argenta.

Sensitive, Confidential, or Privileged Information

[redacted]

Figure 10. Three sets of CO_2 and brine relative permeability curves used in the model

Boundary Conditions

The top and bottom of the model are no-flow boundaries. The four sides of Eau Claire are closed. The four sides of the Mt. Simon and Argenta are open by attaching an infinite-acting Carter-Tracy analytical aquifer.

Initial Conditions

Initial conditions for the model are given in Table 2.

Table 2. Initial conditions.

Parameter	**Value or Range**	**Units**	**Corresponding Elevation (ft MSL)**	**Data Source**
Temperature	Sensitive, Confidential, or Privileged Information [redacted]	[redacted]	[redacted]	Borehole temperature log
Formation pressure	[redacted]	[redacted]	[redacted]	IBDP reference 0.453 psi/ft
Fluid density	[redacted]	[redacted]	[redacted]	Calculated from salinity, pressure, and temperature (McCain, 1991)
Salinity	[redacted]	[redacted]	[redacted]	Brine chemistry analysis from OEE #1

Operational Information

Operating details are presented in

Table 3.

Table 3. Operating details.

Operating Information	**Injection Well 1**	**Injection Well 2**	**Injection Well 3**
Location (global coordinates) X Y	(DD NAD83) -88.480010 40.485427	(DD NAD83) -88.474625 40.500096	(DD NAD83) -88.479947 40.515829
Model coordinates (ft) X Y	(IL SPE 1201 NAD27) 459215 1390740	(IL SPE 1201 N27) 460722 1396081	(IL SPE 1201 N27) 459251 1401815
No. of perforated intervals	1	1	1
Perforated interval (ft MSL) Z top Z bottom	 5,417 5,649	 5,374 5,563	 5,327 5,502
Wellbore diameter (in.)	12.25	12.25	12.25
Planned injection period Start Year End Year	 2025 2045	 2025 2045	 2025 2045
Injection duration (years)	20	20	20
Injection rate (tonne/day)	4,110	4,110	4,110

Fracture Pressure and Fracture Gradient

At the time of this modeling, OEE #1 injection testing was not completed; Sensitive, Confidential, or Privileged Information [redacted] Calculated fracture gradient and maximum injection pressure values are given in Table 4.

Table 4. Injection pressure details.

Injection Pressure Details	**Injection Well 1**	**Injection Well 2**	**Injection Well 3**
Fracture gradient (psi/ft)	Sensitive, Confidential, or Privileged Information [redacted]		
Maximum injection pressure (90% of fracture pressure) (psi)			
Elevation corresponding to maximum injection pressure (ft MSL)			
Elevation at the top of the perforated interval (ft MSL)			
Calculated maximum injection pressure at the top of the perforated interval (psi)			

Computational Modeling Results

Predictions of System Behavior

The CO_2 plume was defined by CO_2 saturation of 1%. The pressure front area is where the pressure change is greater than or equal to the critical differential pressure.

Figure 11 shows the pressure front (only) at 5, 10, and 20 years. Figure 12 shows the CO_2 plume superimposed over the pressure front at the end of injection.

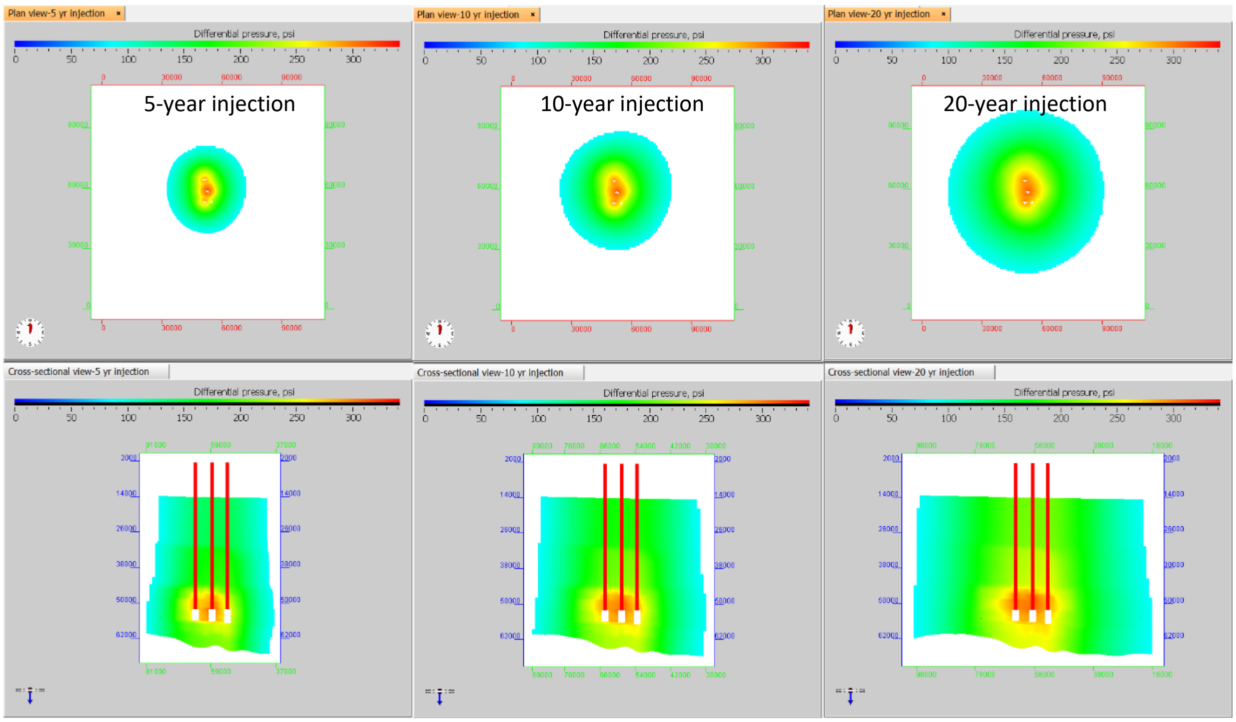

Figure 11. Plan and cross-sectional views of pressure front at 5, 10, and 20 years of injection (scale on each image is in feet).

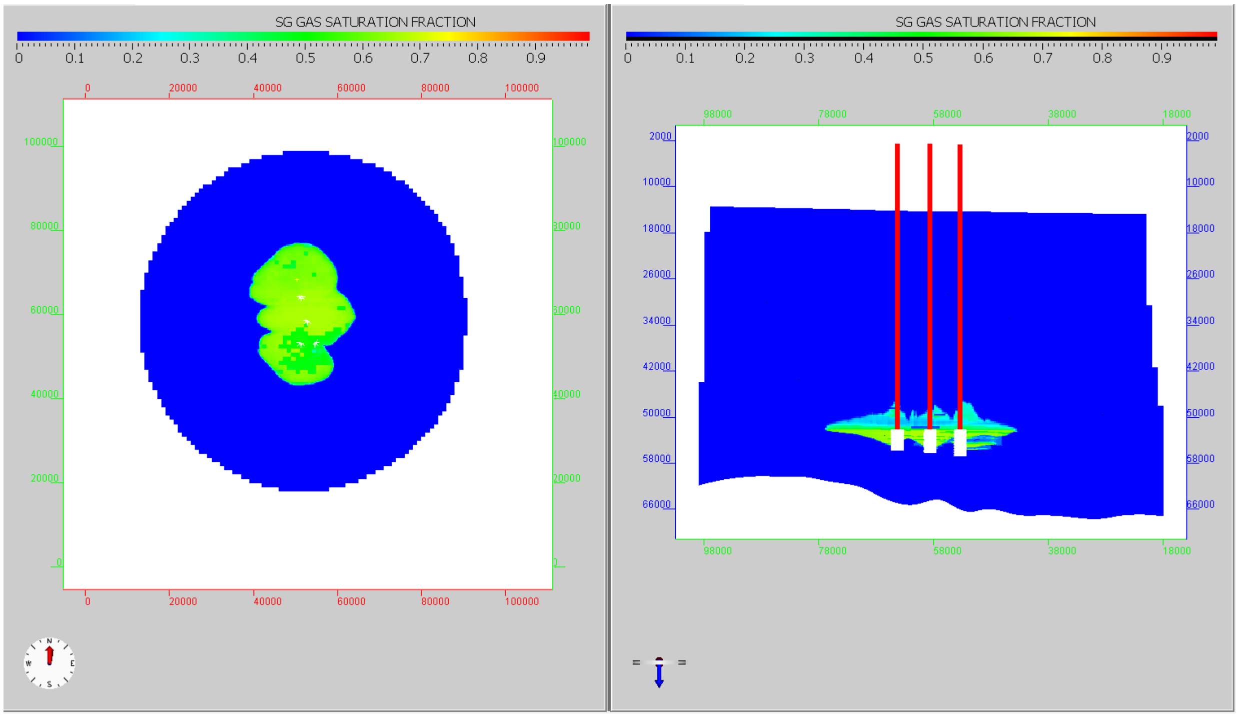

Figure 12. Plan and cross-sectional views of CO_2 saturation outlined by critical differential pressure front at the end of injection. Model coordinates (ft) are labeled on images. The plan view coordinates at the corners (in Decimal Degree NAD83) of: NE: -88.28294193, 40.63582357; SE: -88.28294299, 40.34439485; SW: -88.6648716, 40.34439586; NW: -88.66486794, 40.63582328.

Figure 13 shows the CO_2 plume and pressure front evolution with time. At the end of injection, the CO_2 plume was 32 square miles (83 square kilometers), and the pressure front reached its maximum of 178 square miles (461 square kilometers). The CO_2 plume did not increase following cessation of injection.

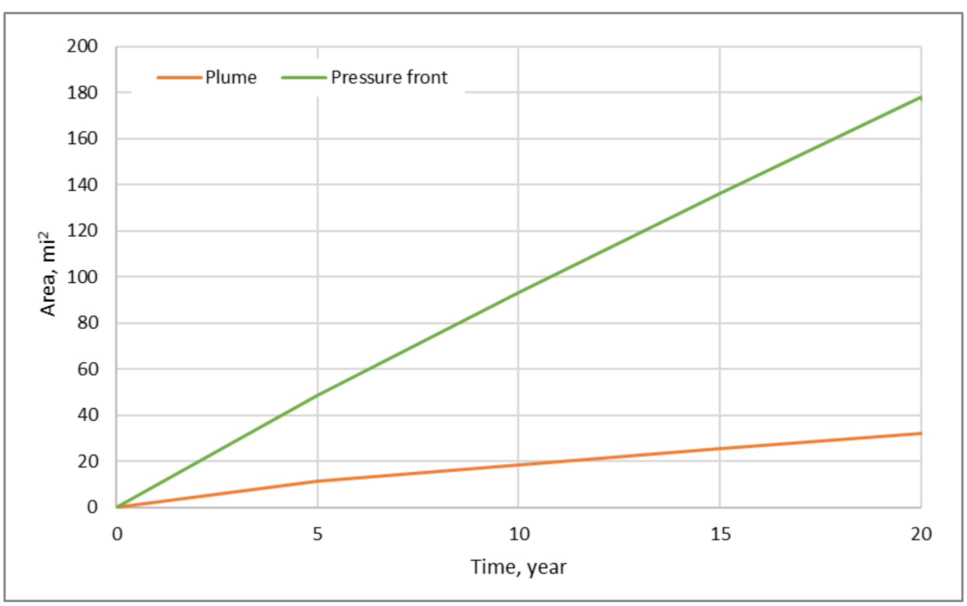

Figure 13. Area of CO_2 plume and pressure front change with time for 1 mile distance between injection wells

Model Calibration and Validation

Two sets of sensitivity analysis were conducted on CO_2 plume size and pressure front: 1) injection well spacing and 2) the sensitivity of porosity and permeability.

The arkose interval is perforated according to Table 3. OES #1 was 0.6 miles (1 kilometer) away from OEE #1 to ensure CO_2 plume detection at OEE #1.

Well distance: Three well distances between the injectors were considered: 1 mile, 1.5 miles, and 2 miles (1.6, 2.4, and 3.2 kilometers). Simulation results showed that 1 mile distance resulted in the smallest CO_2 plume (34 square miles; 88 square kilometers) (Figure 14). The pressure front was the same among all three distances (Figure 15). Therefore, the distance between the three injectors (

Table 3) was 1 mile (1.6 kilometer).

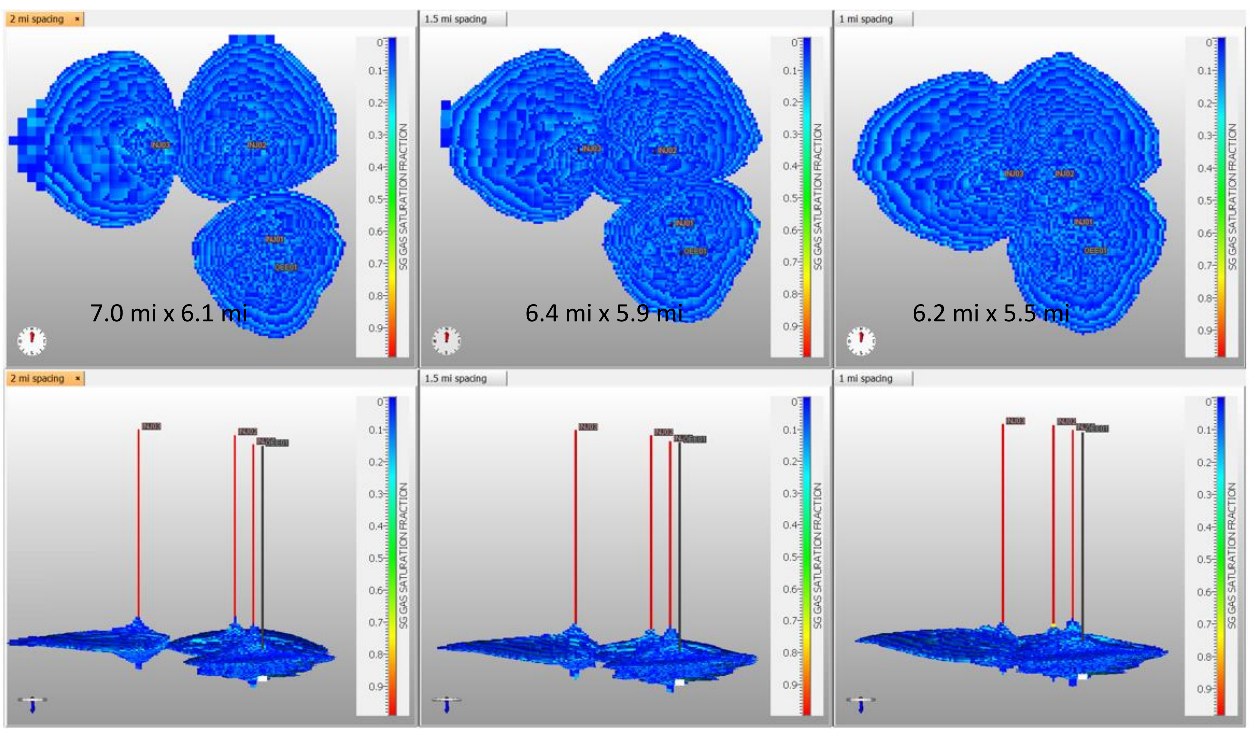

Figure 14. Plan and cross-sectional views of CO_2 plume at various well distances. (Distance between wells in upper left corner of each view.) Vertical exaggeration is 10x.

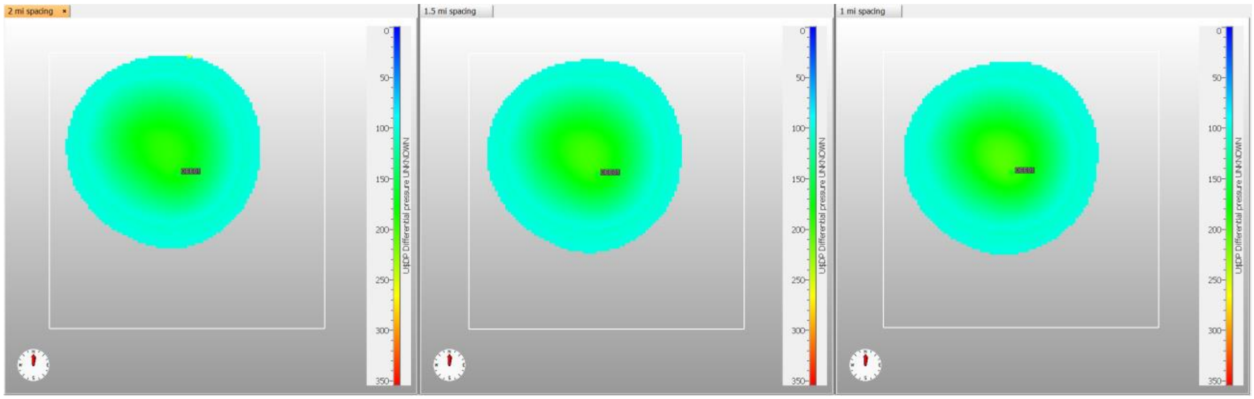

Figure 15. Pressure front at the end of injection at three well distances. Distance between wells in upper left corner of each view. OEE #1 shown. The white, square box is 20 miles by 20 miles.

Porosity and permeability: an 80 and 120% multiplier to the geocellular porosity and permeability models showed that an increase in porosity slightly decreased CO_2 plume size but had little effect on pressure front. A change in permeability had little effect on CO_2 plume size and pressure front.

<u>AoR Delineation</u>

Critical Pressure Calculations

The pressure front is defined by the extent of the critical differential pressure (Δp_{crit}), the minimum pressure increase in the injection zone that initiates fluid flow from the injection zone into the deepest underground source of drinking water (USDW) through a notional conduit (White et al. 2019, Nicot et al., 2009). The approach for estimating the minimum pressure in this study assumes fluid density in the wellbore to be uniform and equal to the fluid density in the injection zone (Birkholzer et al., 2011).

The critical differential pressure of the Mt. Simon Sandstone is calculated using the following equation (Birkholzer et al., 2011):

$$\Delta p_{crit} = p_u + \rho_i g(z_i - z_u) - p_i \quad (1)$$

$$\Delta \mathrm{p_{crit}} = 1025 + \left(\frac{70.08}{144}\right)(5435 - 1540) - 2835 \quad (1a)$$

Table 6 defines equation 1 variables (except for g, which is the acceleration due to gravity). At OEE #1, the USDW is the St. Peter Sandstone, and the target storage formation is the Mt. Simon Sandstone. Table 6 lists Δp_{crit} and the parameters used in equation 1.

Table 5: Inputs used to calculate Δp_{crit} at OEE #1.

Parameters		Value	Data source
Input	Depth at base of St. Peter Sandstone, z_u	Sensitive, Confidential, or Privileged Information [redacted]	
	Initial pressure at base of St. Peter Sandstone, p_u		
	Depth to perforation zone (Top of Arkose interval, z_i		

	Initial pressure at perforation zone (Top of Arkose interval), p_i	Sensitive, Confidential, or Privileged Information [redacted]
	Brine density in MSS, ρ_i	
Output	Δp_{crit}	

AoR Delineation

As indicated by EPA, “The boundaries of the AoR are based on simulated predictions of the extent of the separate-phase (i.e., supercritical, liquid, or gaseous) plume and pressure front” (USEPA, 2013). Area of Review (AoR) is the greater of either the maximum areal extent of CO_2 plume or pressure front, or a combination of the two, over the duration of a storage project.

The critical differential pressure of 86 psi (593 kPa) defined the pressure front in the previous section. Because the pressure front is larger than the CO_2 plume, the pressure front in Figure 13 is the AoR change with time.

Figure 16 shows the AoR after 20 years of injection, overlain on a topographic map of the area around the project wells. The AoR is based on the pressure front and is approximately 178 square miles (461 square kilometers).

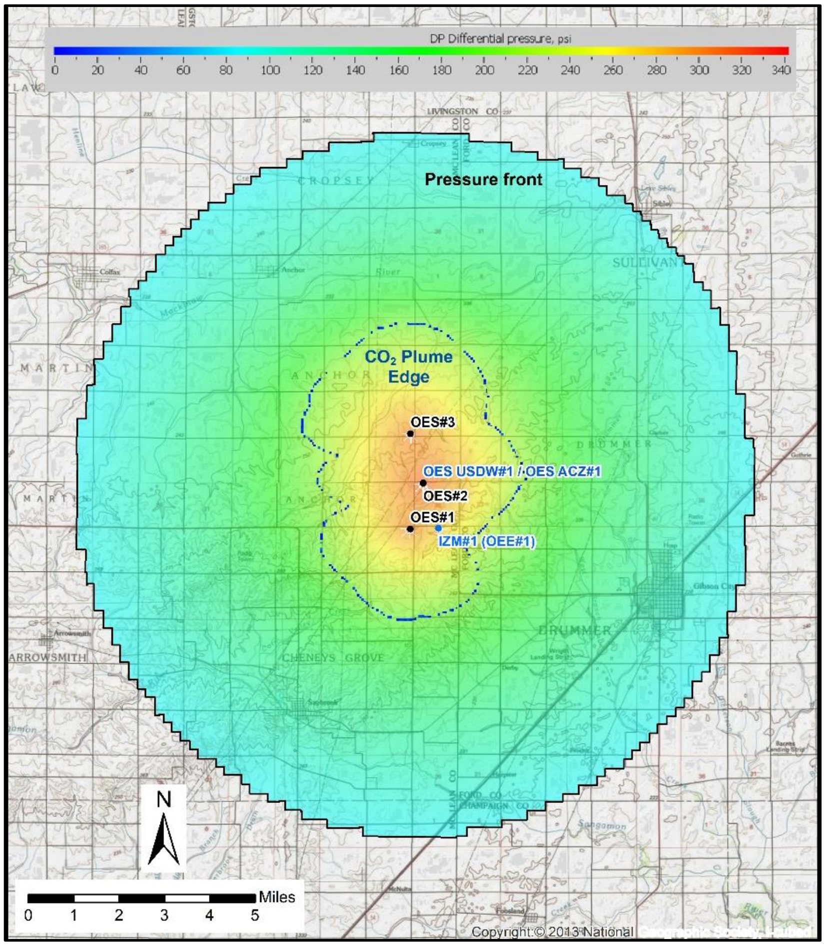

Figure 16. Predicted maximum AoR at 20 years of injection, shown overlain on a topographic map of the immediate area around the project wells. The map corner coordinates (Decimal Degree NAD83) are: NE: NE = -88.309199, 40.653973; SE = -88.309307, 40.352654; SW= -88.648213, 40.352227; NW= -88.649625, 40.653543.

Corrective Action

Tabulation of Wells within the AoR

Wells within the AoR

The ISGS Wells and Borings Database and the ISGS coal stratigraphic database were the sources of the tabulated wells. Sensitive, Confidential, or Privileged Information [redacted] a table detailing the identifying information, location, depth, and status of these wells and borings was uploaded to the GSDT tool.

Sensitive, Confidential, or Privileged Information [redacted]

There are oil and gas wells and other wells or borings described as stratigraphic test wells, engineering borings, coal test holes, and a coal mine shaft. Two of the non-water wells and borings were completed to depths between 2,000 and 3,000 feet (610 and 914 meters).

The Erp #1 has a TD *within* the Eau Claire Formation and *does not fully penetrate* the Eau Claire. The Erp #1 well was drilled for oil in the early 1940s and is Dry and Abandoned. Based on the Erp #1 TD (4,250 feet; 1,295 meters), Erp #1 Eau Claire top (3,805 ft), and the Eau Claire regional thickness (550 feet), it is unlikely that the well fully penetrated the Eau Claire Formation. An estimated 105 feet (32 meters) of the Eau Claire Formation remains below the TD of Erp #1. Additionally, the Erp #1 records indicate the TD is in the Eau Claire.

The possibility exists that there are other historical coal test holes in the area that may not be captured in the queried data sources, but these holes (if present) would be expected to be less than 600 feet (183 meters) deep based on the regional trend of coals mapped through the area.

Sensitive, Confidential, or Privileged Information

[redacted]

Figure 17. Wells and borings located within the AoR. USGS topographic base map. Project wells are labeled in larger bold print, and the Erp #1 well is highlighted in yellow. The map corner coordinates (Decimal Degree NAD83) are: NE: -88.309189, 40.681881; SE: -88.309316, 40.324745; SW -88.648083, 40.324319; NW -88.649757, 40.681450.

Wells Penetrating the Confining Zone

The only well that fully penetrates the Eau Claire Formation is OEE #1.

According to the EPA, if a well is not fully penetrating the confining zone then no further action is needed (US EPA, 2013).

Plan for Site Access

No well fully penetrated the confining zone; therefore, no corrective action plan is required.

Corrective Action Schedule

Not applicable.

<u>Reevaluation Schedule and Criteria</u>

AoR Reevaluation Cycle

One Earth Sequestration, LLC will reevaluate the above described AoR every five years during the injection and post-injection phases.

The procedure below will be followed for the AoR reevaluation:

1) Input the actual injection rates into the model and simulate from inception to the time of the AoR reevaluation: the CO_2 plume, pressure front, pressure and saturation of the projects' wells.

2a) compare the measured pressure and saturation vs. time for all project wells to the simulation results, and/or

2b) compare the estimates of the CO_2 plume inferred from seismic to the simulated CO_2 plume.

3a) If 2a and 2b compare within triggers (next section), calibrate the model to the measured data for use in the next reevaluation cycle, or

3b) if 2a and/or 2b does not compare within triggers (next section), calibrate the model to the measured data and repeat process by starting at 2a).

4) Compare the AoR to the CO_2 plume and pressure front simulated in steps 2) - 3)

5) Decide if AoR estimated for permit should be updated.

Triggers for AoR Reevaluations Prior to the Next Scheduled Reevaluation

Changes to trends in injection rate, pressure change, and saturation with time at project wells, and CO_2 plume estimates based on seismic surveys may trigger an AoR reevaluation. Only quantitative thresholds expected to increase AoR substantially are included. The following may trigger a reevaluation:

- Rate: 50% increase over 12 months
- Pressure change: >50 psi and 50% above simulated pressure.
- Saturation: CO_2 saturated interval (height) less than 50% of the simulated height
- CO_2 plume: Area of CO_2 plume greater than 50% of the simulated area of CO_2 plume or any single edge of the CO_2 plume exceeding 80% of the radius of the simulated plume edge.

One Earth Sequestration, LLC will discuss any such events with the UIC Program Director to determine if an AoR reevaluation is required. If an unscheduled reevaluation is triggered, One Earth Sequestration, LLC will perform the steps described at the beginning of this section of this Plan.

Plan revision number: [INSERT]
Plan revision date: [INSERT]

References

Birkholzer, J.T., Nicot, J.P., Oldenburg, C.M., Zhou, Q., Kraemer, S., Bandilla, K.W. (2011): Brine Flow up a Well Caused by Pressure Perturbation from CO_2 Storage: Static and Dynamic Evaluations, International Journal of Greenhouse Gas Control, 5(4), pp. 850-861, https://www.sciencedirect.com/science/article/pii/S1750583611000041.

Buschbach, T. C., 1964, Cambrian and Ordovician strata of northeastern Illinois: Illinois State Geological Survey Report of Investigations 218, 90 p.

Corey, A.T. 1954. The interrelation between gas and oil relative permeabilities. Producers Monthly 19 (November): 38–41.

McCain Jr., W.D. 1991. Reservoir-Fluid Property Correlations-State of the Art. SPE Res Eng 6 (2): 266-272. SPE-18571-PA.

Newman, G.H., 1973. Pore-Volume Compressibility of Consolidates, Friable, and Unconsolidated Reservoir Rocks under Hydrostatic Loading. SPE 3835. Presented at SPE Rocky Mountain Regional Meeting, held in Denver, Colorado, 10-12 April 1972.

Nicot, J., Oldenburg, C., Bryan, S., and Hovorka, S., 2009, Pressure perturbations from geologic carbon sequestration: Area-of-review boundaries and borehole leakage driving forces, Energy Procedia, Volume 1, Issue 1, 2009, Pages 47-54, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2009.01.009.

Peng, D. Y. and D. B. Robinson, 1976, A new two-constant equation of state, Ind. Eng. Chem. Fundam. V. 15, p. 59-64.

U. S. Environmental Protection Agency, 2013. Geological Sequestration of Carbon Dioxide Underground Injection Control (UIC) Program Class VI Well Area of Review Evaluation and Corrective Action, Guidance 96.

White, S., Carroll, S., Chu, S., Bacon, D., Pawar, R., Cumming, L., Hawkins, J., Kelley, M., Demirkanli, I., Middleton, R., Sminchak, J., Pasumarti, A., A risk-based approach to evaluating the Area of Review and leakage risks at CO_2 storage sites, International Journal of Greenhouse Gas Control, Volume 93, 2020, 102884, ISSN 1750-5836, https://doi.org/10.1016/j.ijggc.2019.102884.